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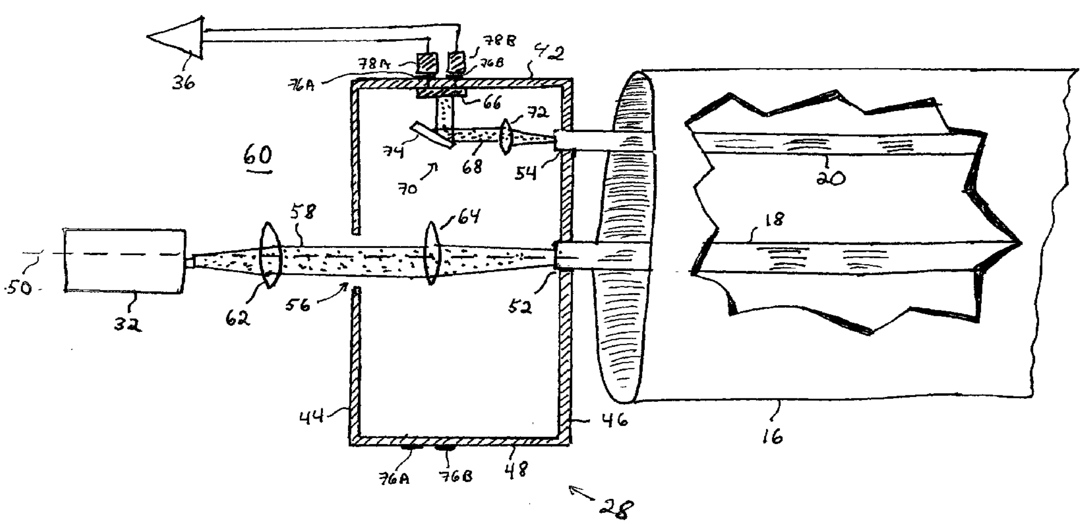
(54) Title: MULTI-CHANNEL OPTICAL COUPLER FOR SPINNING CATHETER



(57) Abstract: A system for identifying vulnerable plaque includes a catheter (16) having a collection fiber (20) and a delivery fiber (18) therethrough. The catheter (16) is engaged to a distal face (46) of a housing (42) configured to spin about an axis. The proximal face (44) of the housing (42) has a central aperture (56). First (64) and second (70) optical relays extend respectively between the central aperture (56) and a central port (52) on the distal face (46) and between a detector (66) and an eccentric port (54) on the distal face. The central (52) and (eccentric54) ports are in optical communication with the delivery (18) and (20) collection fibers respectively.

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MULTI-CHANNEL OPTICAL COUPLER FOR SPINNING CATHETER

FIELD OF INVENTION

This invention relates to catheters, and in particular, to catheters that accommodate more than one optical fiber.

BACKGROUND

Vulnerable plaques are lipid filled cavities that form within the wall of a blood vessel. These plaques, when ruptured, can cause massive clotting in the vessel. The resultant clot can interfere with blood flow to the brain, resulting in a stroke, or with blood flow to the coronary vessels, resulting in a heart attack.

To locate vulnerable plaques, one inserts a catheter through the lumen of the vessel. The catheter includes a delivery fiber for illuminating a spot on the vessel wall and one or more collection fibers for collecting scattered light from corresponding collection spots on the vessel wall. The delivery fiber, and each of the collection fibers form distinct optical channels within the catheter. The catheter used for locating plaques is thus a multi-channel catheter.

In operation, a light source outside the catheter introduces light into the delivery fiber. A detector, also outside the catheter, detects light in the collection fiber and generates an electrical signal representative of that light. This signal is then digitized and provided to a processor for analysis.

A vulnerable plaque can be anywhere within the wall of the artery. As a result, it is desirable to circumferentially scan the illuminated spot and the collection spot around the vessel wall. One way to do this is to spin the multi-channel catheter about its axis. However, since neither the light source nor the processor spin with the catheter, it becomes more difficult to couple light into and out of the delivery and collection fibers while the catheter is spinning.

SUMMARY

The invention features a multi-channel coupler that spins synchronously with a catheter having optical fibers extending through it. Each fiber defines an optical channel. The coupler enables stationary equipment to couple light beams or signals

representative of light beams into or out of each fiber separately from all other fibers, even while the catheter spins about its axis.

In one aspect, the invention includes a multi-channel optical coupler having a housing configured to spin about an axis. The housing has a proximal face with a central aperture that intersects the axis. The coupler includes at least two optical relays: a first optical relay that guides the first beam from the central aperture to a central port on the distal face; and a second optical relay for guiding a second beam to a detector from an eccentric port on the distal face.

Some embodiments of the invention include a first optical relay having a stationary lens disposed to direct the first beam onto the central aperture. In some of these embodiments, a focusing lens is disposed between the stationary lens and the central port. In yet other embodiments, the first optical relay includes a graduated index of refraction ("GRIN") lens seated in the central aperture, the GRIN lens being configured to direct the first beam to the central port.

The invention includes embodiments that feature variations of the second optical relay. Among these are embodiments in which the second optical relay includes a collimating lens within the housing. This collimating lens is disposed to guide the second beam entering the housing at the eccentric port toward a detector mounted on an inner wall of the housing. In some of these embodiments, the second optical relay further includes a light-directing element disposed to direct the second beam toward a peripheral wall of the housing.

Additional variations of the second optical relay are those found in embodiments featuring one or more eccentric apertures in the proximal face of the housing. These eccentric apertures allow passage of one or more corresponding second beams. These beams trace paths on an annular mirror outside the housing as the housing spins.

In some embodiments, the annular mirror features a mirror aperture disposed to permit the first beam to pass therethrough. In others, the annular mirror is disposed to direct a path traced by the one or more second beams onto a stationary detector.

Another aspect of the invention is a system for identifying vulnerable plaque. In one embodiment, the system includes a catheter having a collection fiber and a delivery fiber extending therethrough. The catheter engages a distal face of a housing configured to spin about an axis. The proximal face of the housing has a central aperture in optical communication with a central port on the distal face by way of a first optical relay that extends therebetween. A second optical relay extending between a detector and an eccentric port on the distal face provides optical communication with the collection fiber.

In an additional aspect, the invention provides a way to optically couple to a collection fiber and a delivery fiber. In one practice, the method includes transmitting a delivery beam into a central aperture of a housing and guiding the delivery beam from the central aperture to a central port in the housing, the central port being in optical communication with the delivery fiber. A collection beam is then received from an eccentric port in the housing, the eccentric port being in optical communication with the collection fiber. The collection beam is then guided to the detector.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

Embodiments of the invention may have one or more of the following advantages. By providing a continuous connection to both optical fibers, the rotary coupler permits the entire circumference of an artery to be scanned automatically.

A rotary coupler having the features of the invention can also be used to identify other structures outside but near a lumen, or on the surface of the lumen wall. For example, cancerous growths within polyps can be identified by a catheter circumferentially scanning the lumen wall of the large intestine, cancerous tissue in the prostate may be identified by a catheter scanning the lumen wall of the urethra in the vicinity of the prostate gland, or Barrett's cells can be identified on the wall of the esophagus. In addition to its medical applications, the rotary coupler can be used in industrial applications to identify otherwise inaccessible structures outside pipes.

Other features and advantages of the invention will be apparent from the following detailed description, and from the claims.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a system for identifying vulnerable plaque in a patient.

FIG. 2 is a cross-section of the multi-channel catheter in FIG. 1.

FIGS. 3 and 5-6 are multi-channel couplers incorporating the invention.

FIG. 4 is an end view of the multi-channel coupler of FIG. 1.

DETAILED DESCRIPTION

System Overview

FIG. 1 shows a diagnostic system **10** for identifying vulnerable plaque **12** in an arterial wall **14** of a patient. The diagnostic system features a catheter **16** to be inserted into a selected artery, e. g. a coronary artery, of the patient. A delivery fiber **18** and a collection fiber **20** extend between a distal end **21** and a proximal end **23** of the catheter **16**.

As shown in FIG. 2, the catheter **16** includes a jacket **17** surrounding a rotatable core **19.** The delivery fiber **18** extends along the center of the core **19** and the collection fiber **20** extends parallel to, but radially displaced from, the delivery fiber **18**. The rotatable core **19** spins at rate between approximately 4 revolutions per minute and 30 revolutions per minute.

At the distal end **21** of the catheter **16**, a tip assembly **22** directs light traveling axially on the delivery fiber **18** toward an illumination spot **24** on the arterial wall **14**. The tip assembly **22** also collects light from a collection spot **26** on the arterial wall **14** and directs that light into the collection fiber **20**.

A multi-channel coupler **28** driven by a motor **30** engages the proximal end **23** of the catheter **16**. When the motor **30** spins the multi-channel coupler **28**, both the coupler **28** and the catheter **16** spin together as a unit. This feature enables the diagnostic system **10** to circumferentially scan the arterial wall **14** with the illumination spot **24**.

In addition to spinning the catheter **16**, the multi-channel coupler **28** guides light from a laser **32** (or other light source, such as an LED, a super luminescent LED, or an arc lamp) into the delivery fiber **18** and guides light emerging from the collection fiber **20** into one or more detectors (not visible in FIG. 1). The multi-channel coupler **28** performs these tasks even as it spins the catheter **16**.

The detectors provide an electrical signal indicative of light intensity to an amplifier **36** connected to an analog-to-digital ("A/D") converter **38**. The A/D converter **38** converts this signal into data that can be analyzed by a processor **40** to identify the presence of a vulnerable plaque **12** hidden beneath the arterial wall **14**.

Coupler Fixed to Catheter

A multi-channel coupler **28** for carrying out the foregoing tasks, as shown in FIG. 3, includes a cylindrical housing **42** having a proximal face **44** joined to a distal face **46** by a peripheral wall **48**. A bearing (not shown) supports the housing **42** and enables it to spin about an imaginary axis **50** that intersects the proximal and distal faces **44, 46** thereof.

The distal face **46** of the housing **42** is coupled to the catheter **16**. Two optical fibers extend through the catheter **16**: a delivery fiber **18** for illuminating the arterial wall **14** and a collection fiber **20** that collects light scattered from the arterial wall **14**. The catheter **16** and the housing **42** spin together about the same axis **50**.

The distal face **46** of the housing **42** has a central port **52** for receiving the delivery fiber **18** and an eccentric port **54** for receiving the collection fiber **20**. The central port **52** is located at the intersection of the axis **50** with the distal face **46**. The eccentric port **54** is radially displaced from the central port **52**. As a result, when the catheter **16** and the housing **42** spin about their common axis **50** the delivery fiber **18** remains stationary and the collection fiber **20** traces out a circular path, as shown in an end view in FIG. 4.

At its intersection with the axis **50**, the proximal face **44** has a central aperture **56** for receiving a delivery beam **58** from a laser **32** across a gap **60**. The delivery beam **58** can be directed toward the central aperture **56** by pointing a laser **32** as shown, by providing an optical relay to direct the delivery beam **58** to the central aperture **58**, or by guiding the delivery beam **58** toward the central aperture **58** along an optical fiber. This central aperture **56**, like the central port **52** on the distal face **46**, remains stationary even as the housing **42** spins about the axis **50**.

A first collimating lens **62** collimates the delivery beam **58** and directs it into the housing **42** through the central aperture **56**. A first optical relay **64** within the housing **42** then receives the collimated delivery beam **58** and directs it distally across the housing **42** toward the central port **52**, where it enters the delivery fiber **18**. As used herein, an optical relay refers to a set of optical elements, such as lenses, prisms, and mirrors, arranged to direct light from a source to a destination.

In FIG. 3, this first optical relay **64** includes a converging lens focused at the central port **28**. However, the first optical relay **64** can include components other than, or in addition to that shown in FIG. 1. Between the central port **28** and the central aperture **56**, the delivery beam **58** is not constrained to travel along the axis **50** as shown in FIG. 1.

Also within the housing **42**, mounted on an interior of the peripheral wall **48**, is a detector **66** for receiving a collection beam **68** entering through the eccentric port **54**. A second optical relay **70** receives the collection beam **68** from the eccentric port **54** and directs it to the detector **66**. In FIG. 3, this second optical relay **70** includes a

second collimating lens **72** that receives a diverging collection beam **68** from the eccentric port **34** and directs a collimated collection beam **68** toward a diagonal mirror **74**. The diagonal mirror **74** then reflects the collimated collection beam **68** toward the detector **66**.

The detector **66** is electrically connected to a pair of slip rings **76A-B** on the outer surface of the peripheral wall **48**. A corresponding pair of stationary brushes **78A-B** provides electrical coupling between the slip rings **76A-B** and the amplifier **36**. As the housing **42** spins, the brushes **78A-B** maintain sliding contact with the slip rings, thereby providing a continuous signal to the amplifier **36**.

Detachable Coupler

In another embodiment, shown in FIG. 5, the first optical relay **64** includes a first GRIN ("graduated index of refraction") lens seated in the central aperture **56**. The second optical relay **70** includes a second GRIN lens seated in the eccentric port **54** for directing the collection beam **68** to a detector **66**, now mounted on the inner wall of the proximal face **44**. The slip rings **76A-B** in this embodiment are mounted on the outer surface of the proximal face **44**, where they make sliding contact with the brushes **78A-B** as discussed in connection with FIG. 3.

In this second embodiment, the delivery and collection fibers **18, 20** do not actually penetrate the central and eccentric ports **52, 54**. They are instead held against those ports by a mechanical fitting **80** on the distal face **46** of the housing **42**. This enables the catheter **16** to be easily detached from the multi-channel coupler **28**. Various fittings **80** are available for mechanically coupling to a fiber. Examples include sub-miniature type A connectors ("SMA"), face contact ("FC") connectors, and square connectors ("SC").

Coupler with external detector

A third embodiment, shown in FIG. 6, dispenses with slip rings **76A-B** and brushes **78A-B** altogether by placing a detector **66** outside the housing **42**. In this embodiment, the second optical relay **70** directs the collection beam **68** to an eccentric aperture **82** on the proximal face **44** of, and radially displaced from, the central

aperture **56**. As the housing **42** spins, the collection beam **68**, which emerges from the eccentric aperture **82**, traces a circular path similar to that shown in FIG. 4.

An annular mirror **84** in the gap **60** between the laser **32** and the housing **42** intercepts the circular path traced by the collection beam **68** and reflects it toward a detector **66**. To permit the delivery beam **58** to proceed unimpeded into the central aperture **56** of the housing **42**, the annular mirror **84** features a central hole **86** aligned with the axis **50.**

The geometry of the annular mirror **84** is selected to encompass the path traced out by the collection beam **68** as the housing **42** spins about the axis **50**. The detector **66** must likewise have a shape and extent to encompass the path traced out by the collection beam **68** as reflected by the annular mirror **84**. Alternatively, the annular mirror **84** can be shaped to focus the path traced out on the mirror **84** onto a smaller path on the detector **66.** Or, additional optical elements can be placed in the path followed by the collection beam **68** outside the housing **42** to cause the path traced out by the collection beam **68** to be mapped into another curve.

OTHER EMBODIMENTS

The optical couplers shown in FIGS. 1-6 are two-channel couplers. Each has a delivery channel that carries the delivery beam **58** and a collection channel for carrying a collection beam **68**. However, additional collection channels can be added by providing additional collection ports, each of which is in communication with an additional collection fiber.

As described above, the second optical relay **64** relays scattered light brought to the eccentric port **54** by the collection fiber **20** while the first optical relay **64** delivers light out the central port **52** and into the delivery fiber **18.** However, the collection fiber **20**, the delivery fiber **18**, and the first and second optical relays **64, 70** are all inherently bi-directional. Hence, the delivery fiber **18** and the first optical relay **64** can be used to both deliver light and collect light simultaneously. Similarly, the collection fiber **20** and the second optical relay **64** can be used to both deliver and collect light simultaneously. In addition, the collection fiber **20** and the second optical relay **64** can be used to deliver light while the delivery fiber **18** and the first optical

relay **64** can be used to collect light. The ability of the delivery fiber **18** and the first optical relay **64** to simultaneously deliver and collect light permits the concurrent performance of two or more procedures.

In the embodiments of FIGS. 3 and 5, additional optical relays can be provided to guide the additional collection beams to corresponding detectors. The detectors are them connected to additional slip rings, which relay a signal to the amplifier by way of additional brushes.

In the embodiment of FIG. 6, additional eccentric apertures can be provided in the proximal face. The collection beams emerging from these apertures form concentric nested traces on the annular mirror. The annular mirror then reflects these traces to form concentric traces on the detector. These traces can then be separated from each other by designating signals received from selected pixels of the detector to correspond only to particular collection beams. In particular, the selected pixels on the detector correspond to the loci of the various traces on the detector.

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

We claim:

CLAIMS

1. A multi-channel optical coupler comprising:

a housing configured to spin about an axis, the housing having a proximal face and a distal face;

walls forming a central aperture on the proximal face, the central aperture intersecting the axis;

a first optical relay for guiding a first beam from the central aperture to a central port on the distal face; and

a second optical relay for guiding a second beam to a detector from an eccentric port on the distal face.

2. The optical coupler of claim **1**, wherein the first optical relay comprises a stationary lens disposed to direct the first beam onto the central aperture.

3. The optical coupler of claim **2**, wherein the first optical relay further comprises a focusing lens disposed between the stationary lens and the central port.

4. The optical coupler of claim **1**, wherein the first optical relay comprises a graduated index of refraction lens seated in the central aperture, the graduated index of refraction lens being configured to direct the first beam to the central port.

5. The optical coupler of claim **1**, wherein the second optical relay comprises a collimating lens within the housing, the collimating lens being disposed to guide the second beam entering the housing at the eccentric port toward a detector mounted on an inner wall of the housing.

6. The optical coupler of claim **5**, wherein the second optical relay further comprises a light-directing element disposed to direct the second beam toward a peripheral wall of the housing.

7. The optical coupler of claim **1**, wherein the second optical relay comprises:

walls forming an eccentric aperture in the proximal face of the housing, the eccentric aperture being disposed to permit the second beam to pass therethrough; and

an annular mirror outside the housing, the annular mirror being disposed to intercept a path traced by the second beam emerging from the eccentric aperture as the housing spins.

8. The optical coupler of claim **7**, wherein the annular mirror comprises walls forming a mirror aperture disposed to permit the first beam to pass therethrough.

9. The optical coupler of claim **7**, wherein the annular mirror is disposed to direct a path traced by the second beam onto a stationary detector.

10. The optical coupler of claim **1**, further comprising a slip ring disposed on an outer surface of the housing, the slip ring being in electrical communication with a detector within the housing.

11. A system for identifying vulnerable plaque, the system comprising:

a catheter having a collection fiber and a delivery fiber extending therethrough;

a housing configured to spin about an axis, the housing having a proximal face and a distal face, the proximal face having walls forming a central aperture and the distal face being engaged with the catheter;

a first optical relay extending between the central aperture and a central port on the distal face, the central port being in optical communication with the delivery fiber; and

a second optical relay extending between a detector and an eccentric port on the distal face, the eccentric port being in optical communication with the collection fiber.

12. The system of claim **11**, wherein the first optical relay comprises a lens disposed to receive a delivery beam passing through the central aperture and to direct the delivery beam into the central port.

13. The system of claim **11**, wherein the lens comprises a graduated index of refraction lens seated in the central aperture.

14. The system of claim **11**, wherein the second optical relay comprises a lens disposed in the housing to guide a collection beam from the eccentric port to the detector.

15. The system of claim **11**, wherein the second optical relay comprises:

walls forming an eccentric aperture in the proximal face of the housing, the eccentric aperture being disposed to permit the second beam to pass therethrough; and

an annular mirror disposed outside the housing disposed to intercept a path traced by the collection beam emerging from the eccentric aperture as the housing spins.

16. The system of claim **15**, wherein the annular mirror comprises walls forming a central aperture disposed to allow the collection beam to pass therethrough.

17. The system of claim **15**, wherein the annular mirror is disposed to direct a path traced by the collection beam onto a stationary detector.

18. The system of claim **11**, further comprising a slip ring disposed on an outer surface of the housing, the slip ring being in electrical communication with a detector within the housing.

19. A method for providing optical coupling to a collection fiber and a delivery fiber, the method comprising:

transmitting a delivery beam into a central aperture of a housing;

guiding the delivery beam from the central aperture to a central port in the housing, the central port being in optical communication with the delivery fiber;

receiving a collection beam from an eccentric port in the housing, the eccentric port being in optical communication with the collection fiber; and

guiding the collection beam to a detector.

20. The method of claim **19**, wherein guiding the delivery beam comprises relaying the delivery beam from the central aperture to the central port.

21. The method of claim **19**, wherein guiding the collection beam to the detector comprises relaying the collection beam from the eccentric port to a detector within the housing.

22. The method of claim **19**, wherein guiding the collection beam to the detector comprises:

relaying the collection beam from the eccentric port to an eccentric aperture in the housing; and

relaying the collection beam from the eccentric aperture to a detector outside the housing.

23. The method of claim **22**,wherein relaying the collection beam from the eccentric aperture to the detector comprises reflecting the collection beam off an annular mirror toward the detector.

24. The method of claim **23**,wherein guiding the delivery beam comprises passing the delivery beam through a hole in the annular mirror.

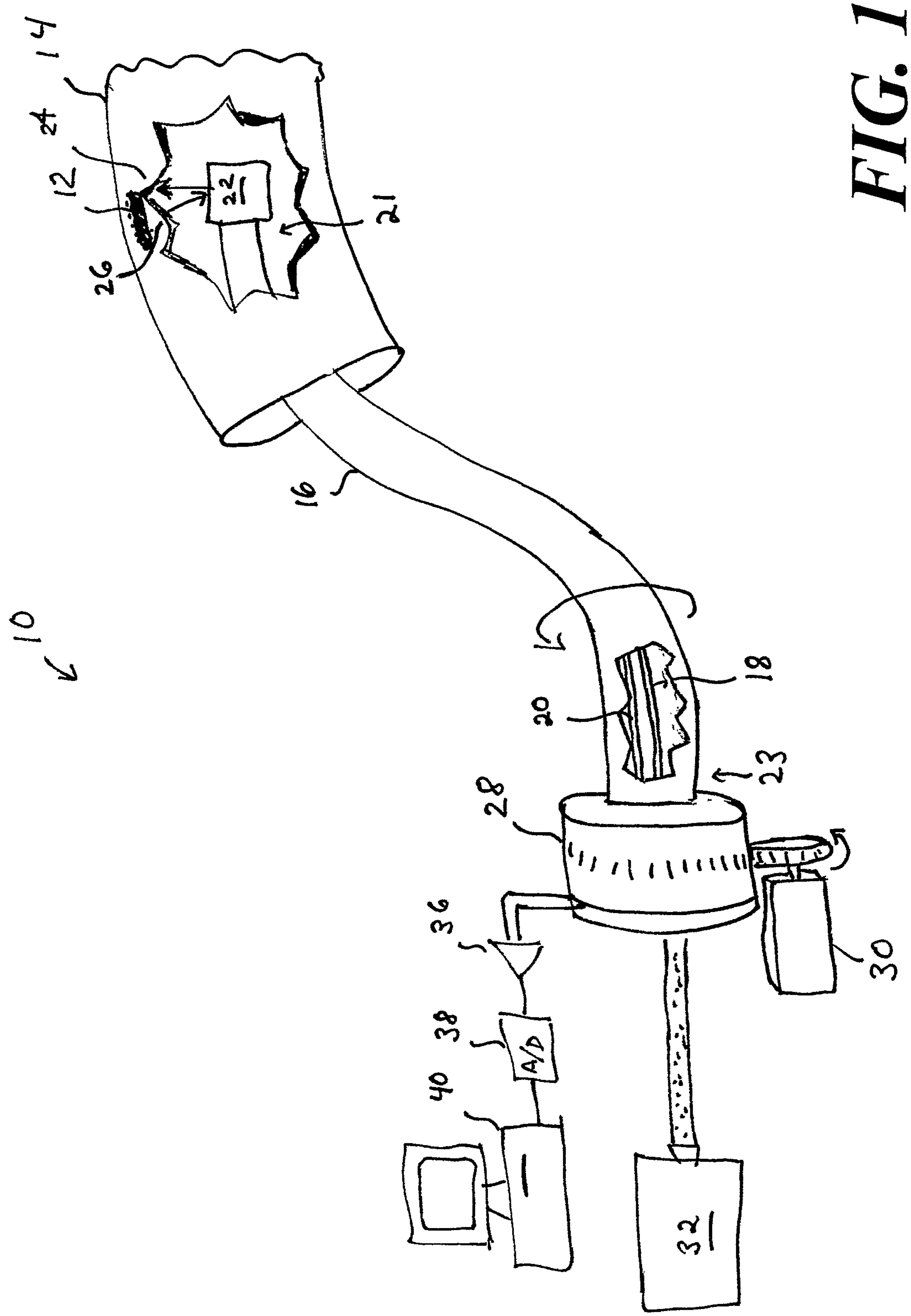

FIG. 1

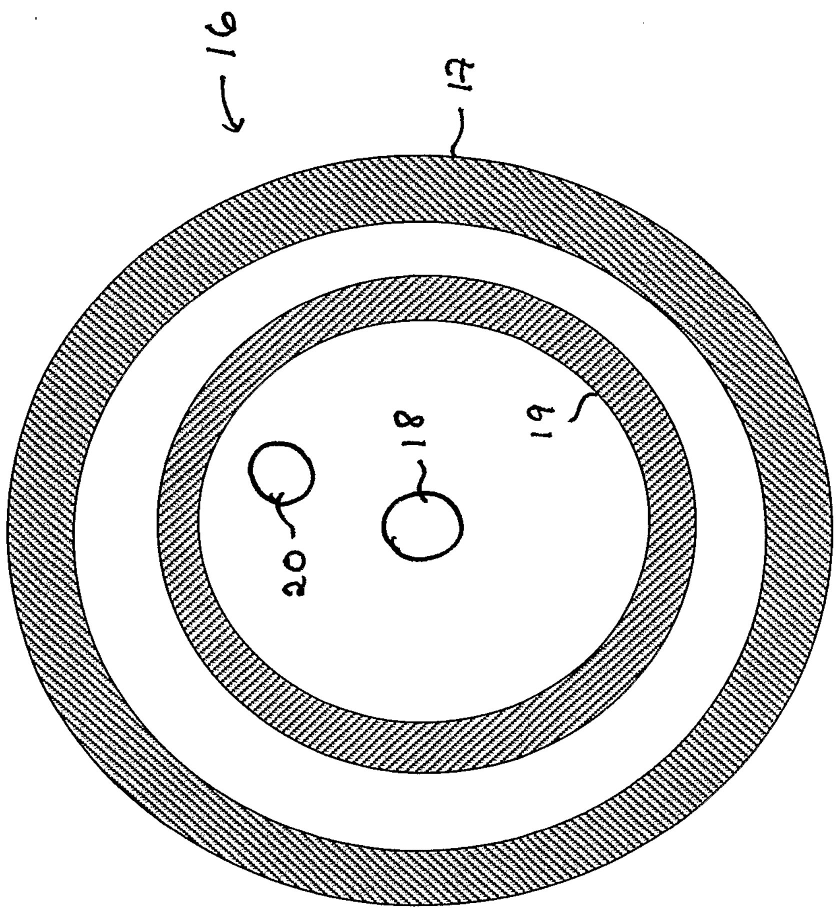

FIG. 2

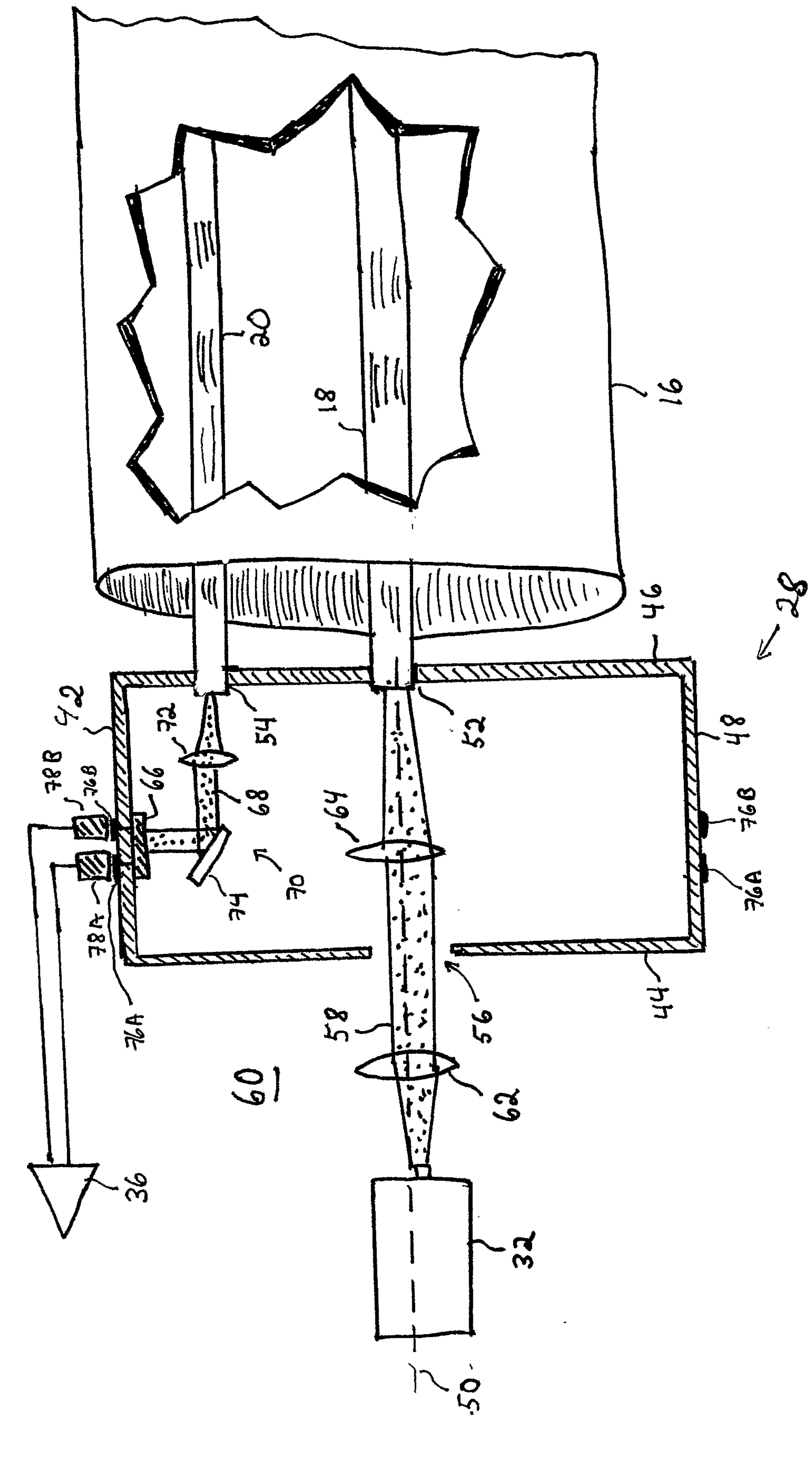
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FIG. 3

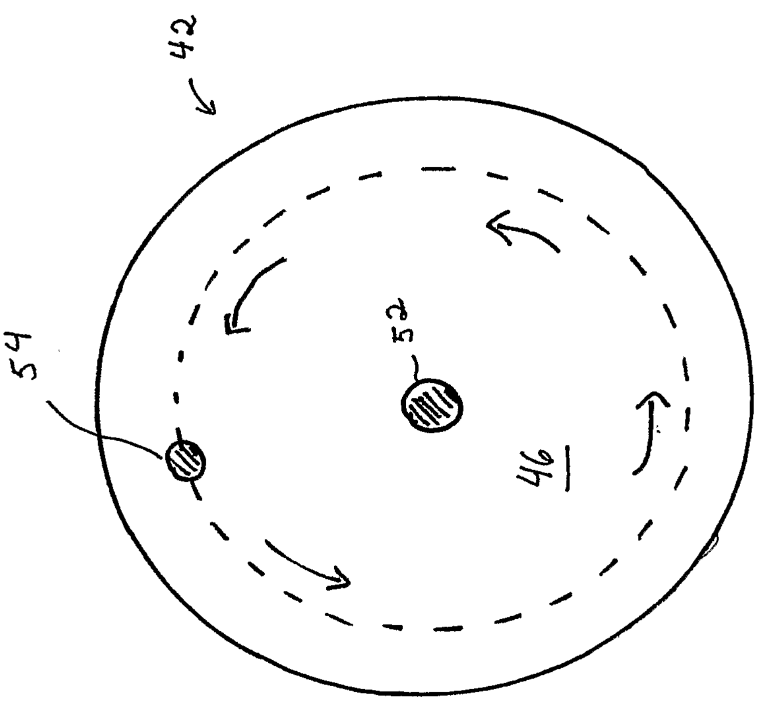

FIG. 4

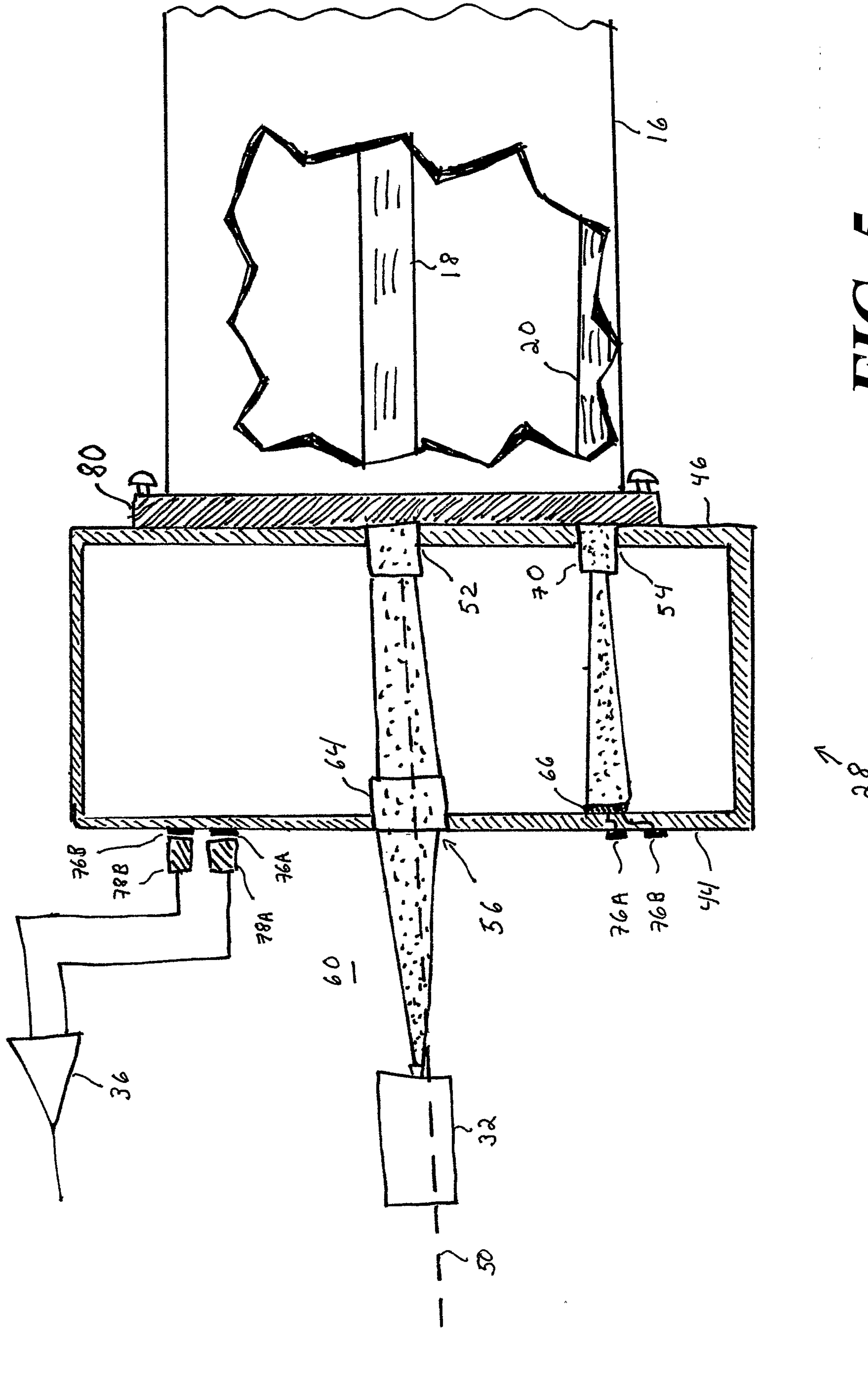
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FIG. 5

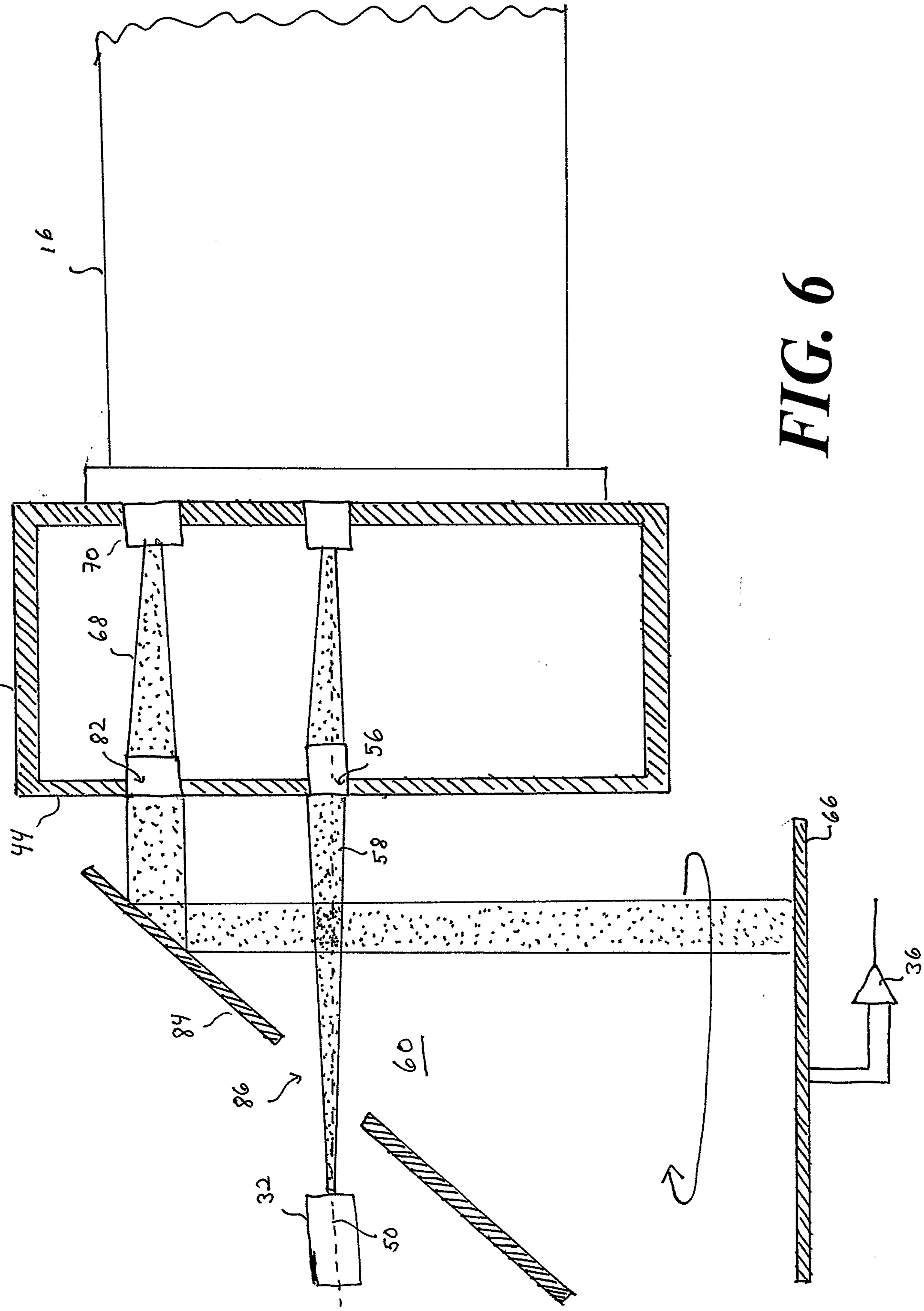

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US03/17832

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G02B 6/00
US CL : 385/39

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 385/22, 31, 39, 117; 600/112, 121; 356/477

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,113,533 A (Howes et al.) 05 September 2000 (05.09.2000), fig. 1	----------- 1-24
X, P	US 6,501,551 B1 (Tearney et al.) 31 December 2002 (31.12.2002), Abstract, figs. 4, 6	1-24

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search	Date of mailing of the international search report
11 August 2003 (11.08.2003)	05 NOV 2003
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703)305-3230	Authorized officer Frank G. Font Diane Smith for Telephone No. 703-308-0956

Continuation of B. FIELDS SEARCHED Item 3:
EAST
terms: detect, sense, measure, rotate, spin, fiber, optic, lens